Jl S. Afr. Bot. 40 (1): 27–45 (1974)

DISCRIMINANT ANALYSIS USED TO DETECT POPULATION VARIATION AMONGST GRASSES COLLECTED ON MINE DUMPS

F. M. Thatcher and R. A. Lubke

(*Botany Department, University of the Witwatersrand*)

Abstract

Quantitative characters are used to show measurable morphological differences between populations of grasses collected from slimes dams and sand dumps of Johannesburg and "natural" populations from other areas. Multivariate discriminant analysis, which considers many characters simultaneously, is used to express numerically the degree of integration between populations as well as variation within each population studied.

Uittreksel

DIE GEBRUIK VAN DISKRIMINANTANALISE OM VARIASIE TUSSEN GRASBEVOLKINGS OP MYNHOPE AAN TE TOON.

Kwantitatiewe eienskappe is gebruik om meetbare morfologiese verskille tussen monsters van grasbevolkings op sekere slykdamme en mynhope van Johannesburg en monsters van "natuurlike" bevolkings van ander plekke aan te dui. Multivariaat diskriminantanalise waardeur verskillende kenmerke gelyktydig behandel word is gebruik om die mate van integrasie tussen plantbevolkings sowel as die variasie binne elke bevolking, numeries uit te druk.

Introduction

The establishment of a vegetative cover on the slimes dams and sand dumps, the waste heaps of Johannesburg and the Reef Mines, not only involves the growing of plants but bringing a plant community into being that will maintain itself (James, 1966).

The material of both slimes dams and sand dumps, the two types of waste dumps created by gold mining operations on the Witwatersrand, is very similar and results from two different extraction processes. Sand dumps are conical heaps with one sloping side (Fig. 1), constituted of finely crushed rock from which the gold is removed by a dry process. This waste material is tipped onto the surface by cocopan. The slimes dams are deposited by pumping a slurry of finely crushed conglomerate onto the surface after the rock has undergone the cyanidization process. Slimes dams are lower in elevation than sand dumps and form square, flat and shallow waste tips (Fig. 1).

The Chamber of Mines established a Vegetation Unit (Fig. 1) whose purpose was to cover the dumps so as to minimise the problem of air and water pollution so prevalent in areas adjacent to the dumps. The first attempts made were those using physical methods; but various plastics, resins and bitumen coatings

---

Accepted for publication 28th September, 1973.

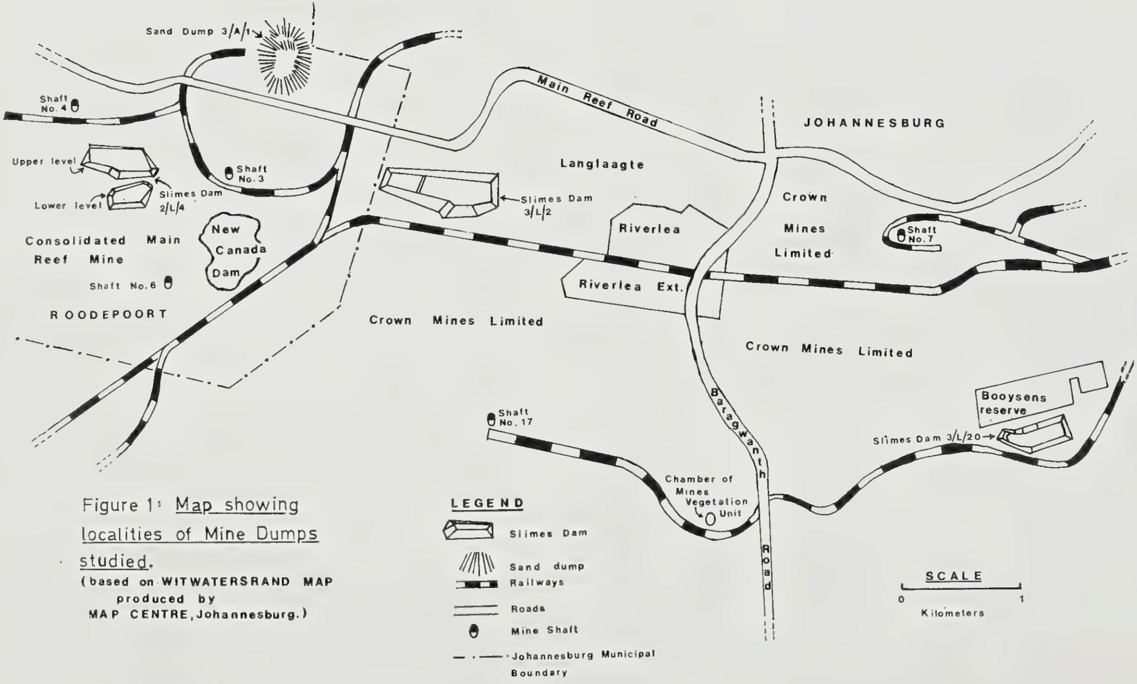


FIG. 1.
Map showing location of Mine Dumps studied.

used proved vulnerable to wind and hail. A cover of stone and soil was tried but this also failed (Cook, 1971). By the end of 1959 it was clear that the best and cheapest method of establishing a permanent cover on the dumps would be to condition the residue to support plant growth (Webster, 1972). This entailed both the correction of very low pH values of the slimes and the extreme acidity resulting from the oxidation of pyrite near the surface. This was followed by selection of plant species, particularly those with slightly acid tolerance ranges and thus suited to this type of environment, for initial plant coverage. A seed mixture containing twenty varieties of Leguminosae and Gramineae was finally used. Chenik (1960, 1963), James and Mrost (1965) and James (1963, 1966) have been the main contributors to research into the establishment of vegetation on the mine dumps.

The present problem is the maintenance of the vegetation cover after initial establishment, as well as the formation of a soil microbial population which will ensure the recycling of essential plant nutrients. The progression towards a more natural grassland and shrub environment is envisaged.

This study, which is more fully presented in Thatcher (1972) has been primarily concerned with populations of indigeneous grasses that have been associated with a trend towards greater stability of this artificially created environment.

"In general sense, a population can be defined as an aggregate of individuals considered together because of their common habitation of a given area at a given time" (Heslop-Harrison, 1960). Dobzhansky (1951) defines the population more precisely as a reproductive community of sexual and cross fertilizing individuals which share a common gene pool. Raup and Stanley (1971) point out that within a living population at any time there is variation due to age differences and *at very least*, this is reflected in the differences in size amongst individuals constituting the population.

This study made use of multivariate discriminant analysis to determine whether or not the variation that exists among plants collected from populations on mine dumps differs statistically from that of those plants collected from populations of the same species growing in "natural" areas on the highveld.

MATERIALS

A total of nine arbitrarily chosen indigeneous species was used: *Eleusine indica* (L.) Gaertn., *Pogonarthria squarrosa* (Licht.) Pilg., *Setaria flabellata* Stapf, *Chloris virgata* Sw., *Hyparrhenia hirta* (L.) Stapf, *Andropogon eucomus* Nees; and three species that were initially included in the seed mixture planted on the dumps, *Paspalum dilatatum* Poir., *Chloris gayana* Kunth and *Cynodon dactylon* (L.) Pers. Each of these species was collected from a minimum of four areas, at least two of the areas being mine dump localities

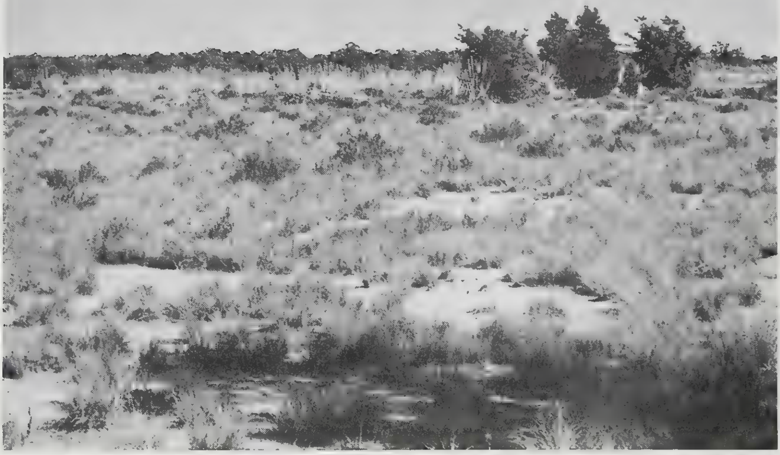
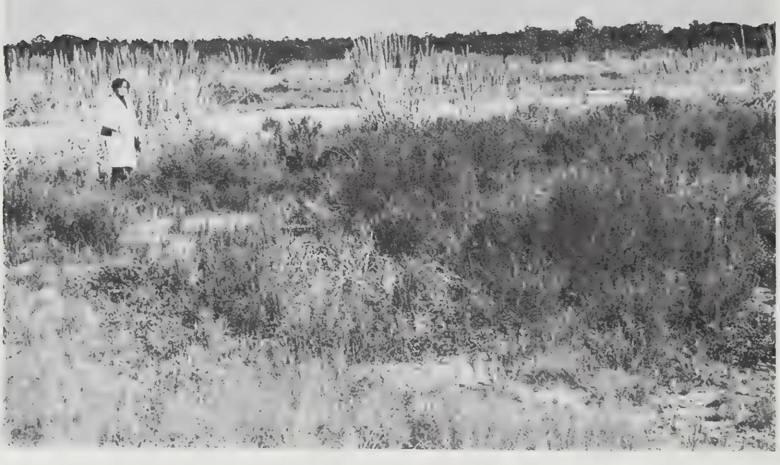


FIG. 2 A and B.
A general view of the top of Booysens Reserve, Crown Mines Slimes Dam 3/L/20, showing the vegetation cover, predominantly grasses.



(Fig. 1). The areas were three slimes dams 3/L/20 Booysens Reserve; Crown Mine Slimes Dam (Fig. 2); 2/L/4 (Lower Level) Consolidated Main Reef Slimes Dam (Fig. 3); 3/L/2 Crown Mine Slimes Dam, and a sand dump 3/A/1 Crown Mines Sand Dump (Fig. 4). Collections were also made from the following "natural" environments of the Transvaal; Pilgrims Rest district; Middelburg district; Krugersdorp district; Witkoppen in the Sandton district; and Frankenwald, Greenside and Parkview in the Johannesburg district. A total of forty-three populations were collected during the period 25th February to 9th April, 1971. The results of only *Pogonarthria squarrosa* (Licht.) Pilg., *Cynodon dactylon* (L.) Pers., *Hyparrhenia hirta* (L.) Stapf and *Chloris gayana* Kunth are reported in this paper.

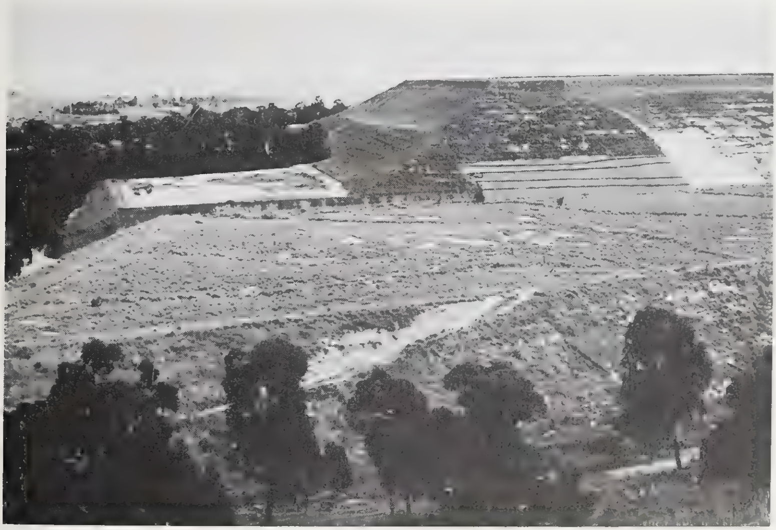


FIG. 3.

A general view of the lower level of 2/L/4 Consolidated Main Reef Slimes Dam, showing its grass cover, with the access road up the side, *Eucalyptus* trees in the foreground.

Twenty "individuals" constituting a culm, a stem terminated by an inflorescence, were cut at ground level from plants chosen at random from each population in the field. Rooting portions of the plant were not considered. All specimens were labelled, pressed and dried, a voucher specimen being deposited in the Moss Herbarium, University of the Witwatersrand.

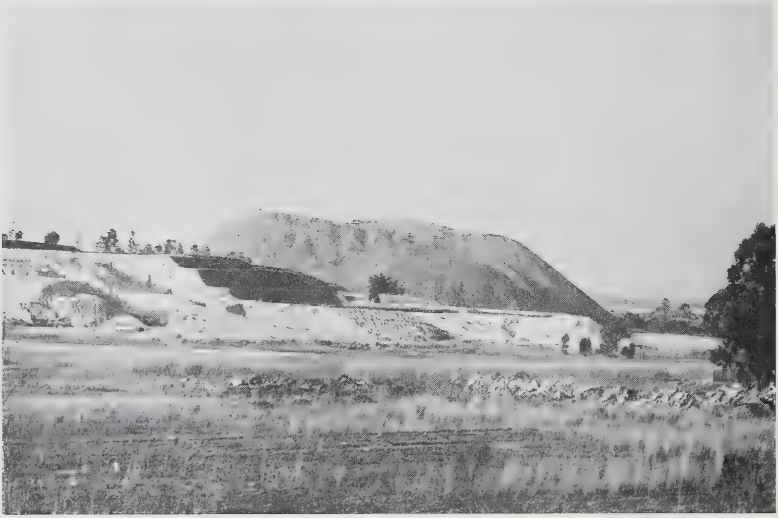


FIG. 4.
The large Consolidated Main Reef Mine Sand Dump 3/A/1.

CHARACTERS

The selection and recording of characters is perhaps the most crucial issue of a numerical study, as an unsuitable selection of characters can change the entire course of an analysis (Ivimey-Cook, 1968). A character is defined as "any attribute referring to form, structure or behaviour which can occur in any one organism as one of two or more mutually exclusive states" (Kendrick, 1964). Quantitative characters, defined as "any character which can be measured and expressed numerically, (Kendrick, 1964), were used in this study. Characters were chosen in order to represent the maximum amount of genetic variation expressed through the morphological characters of the individuals constituting the population. These characters also showed measurable differences when considering different populations. A total of twenty-two characters was used (Table 1). The number of characters used in a single analysis varied from species to species as some characters did not apply to some of the species. This did not affect the analysis as the nine species were analysed separately. Measurements of real or continuous variables corrected to two decimal places were made on each individual, using a brass rule or a micrometer eyepiece fitted to a binocular microscope. The count data consisting of integer values were transformed using a square root transformation. Data matrices or tables were then drawn up taking the form of an $n \times t$ matrix (where n represents characters in rows and t represents twenty individuals in columns).

TABLE 1.

List of characters used in discriminant analysis.

NOTE: All measurements in cm.

Total length of culm from first node at the base of culm
Length of first internode at base of culm
Length of leaf sheath
Length of leaf blade
Width of leaf blade just above ligule
Length from last node to first raceme
Length of inflorescence (total)
Length of individual raceme (lowest one)
Length of spikelet excluding awns
Length of palea
Length of floret
Length of anther
Length of lemma awn
Length of palea awn
Length of grain
Width of grain
Arrangement of spikelets on raceme
Number of nodes per culm
Number of racemes
Number of spikelets per raceme
Number of florets in spikelet
Number of awns

NUMERICAL METHOD

Analysis of the data was by discriminant analysis, using a Fortran IV computer programme (DISCR) written by one of us (R.A.L.), based on the Fortran II programme for multivariate discriminant analysis of Davis and Sampson (1966), on an IBM 360/50 computer. The analysis is essentially a statistical technique of assigning samples to previously defined populations on the basis of a number of variables considered simultaneously (Davis and Sampson, 1966). It is of great value in detecting and establishing a criterion for separating populations. "An important advantage of discriminant function lies in its potentiality of application to individuals. While the functions themselves are primarily population concepts, and their derivation demands knowledge of the bulk variation of the two groups or populations involved, an important property of them in use is that they can be made sensitive enough to place single plants accurately in relation to the average of these groups" not on the basis of one, but on a wide range of characters (Heslop-Harrison, 1952).

This technique involves the calculation of discriminant values (R_1 and R_2) for each population sample and a discriminant index R_0, the dimensional plane which most efficiently separates the clusters of points representing the population. A sample from a third population may be assigned to one or other of the populations depending on which side of R_0 the discriminant values fall. A test for significance (analysis of variance) may be derived from Mahalanobis Generalized Distance (D^2). The contribution that each variable makes to the total distance is calculated and the importance of each character to the analysis can be assessed.

The technique was originally developed by Fisher (1936) as a solution to a taxonomic problem using multiple measurements. He applied this technique to the flowers of three species of *Iris*, and outlined the mathematical implications of the method. This technique has since been used in many other disciplines including geology (Emery and Griffiths, 1954; Mellon, 1964), paleobiometrics (Miller and Kahn, 1962), and taxonomy (Lefebvre and Lennes, 1969). Blackith and Reyment (1971) provide an outline of case histories, derived from various disciplines which use discriminant functions.

Presentation of Results

The results are presented as tables of discriminant values (Tables 2–4), polygonal graphs (Figs. 5, 7, 9 and 11) and scatter diagrams (Figs. 6, 8 and 10). The discriminant tables are modelled on the tables of Krumbein and Graybill (1965) and show discriminant values for twenty individuals from three populations in relation to the calculated values of the discriminant index R_0 and the discriminant values R_1 and R_2 for each population compared.

Polygonal graphs are drawn for each species in order to indicate visually the amount of variation between the different populations studied. The polygonal graph (or polygraph) is a method commonly used in population analysis in order to portray several variables simultaneously (Davis and Heywood, 1963). In each polygonal graph, the eight characters adding the greatest percentage to the analysis are positioned on the eight radii in a clockwise manner in decreasing order of importance. The mean values of each character for the twenty individuals of each population were plotted.

Scatter diagrams were plotted to show the relationship between two of the most important characters. Scatter diagrams show the variation in each character and glyphs for the individuals are plotted where the values for each character intersect (Davis and Heywood, 1963).

Discussion

Table 2 shows the discriminant values calculated for three different populations of *Pogonarthria squarrosa*. An *F value* of *77,28* was obtained when the sand dump (3/A/1) and Frankenwald populations were compared and was highly significant at the 0,1% level, the comparison having a *D^2 value* of *146,84*. Here the Krugersdorp population is seen to be an intermediate population as about half of the discriminant values calculated overlap the sand dump values

TABLE 2.
Discriminant values for three populations of *Pogonarthria squarrosa* (Licht.) Pilg. For explanation, see text, p. 33.

3/A/1 Sand Dump Values	Krugersdorp Values ("Natural" Population)	Frankenwald Values ("Natural" Population)
— 62,388 50		
	— 82,402 82	
— 87,680 31		
— 96,250 43		
— 98,309 51		
— 98,504 01		
— 98,929 78		
— 99,908 23		
	— 100,189 50	
— 102,198 52		
R1— 103,576 9		
— 104,318 73		
— 105,927 06		
— 106,812 38		
	— 107,706 24	
— 108,516 14		
— 109,174 55		
— 109,216 57		
— 109,574 14		
	— 110,662 92	
— 110,727 48		
— 111,701 08		
— 114,551 65		
— 118,292 48		
— 118,557 63		
	— 124,284 48	
	— 146,970 03	
	— 155,869 34	
	— 173,352 17	
	— 174,730 90	
	R ZERO— 176,995 9	
	— 177,331 30	
	— 178,170 85	
	— 187,262 80	
	— 198,156 40	
	— 200,948 20	
	— 204,290 16	
	— 213,611 69	
	— 214,891 31	
	— 218,383 74	
	— 227,225 71	
	— 229,137 82	
		— 232,965 94
		— 234,938 19
		— 235,028 76
		— 235,486 21
		— 239,606 81
		— 241,913 28
		— 242,378 86
		— 243,680 30
		— 245,052 69
		— 250,376 17
		R2— 250,414 9
		— 252,684 94
		— 256,873 29
		— 257,944 34
		— 258,227 54
		— 258,630 62
		— 259,603 52
		— 262,889 40
		— 262,981 93
		— 263,548 34
		— 273,488 04

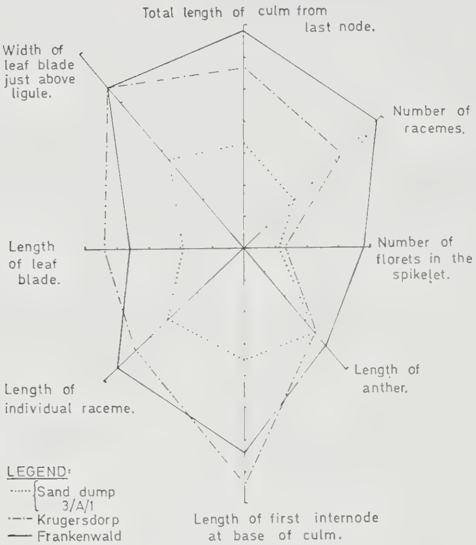


FIG. 5.
Polygonal graph for *Pogonarthria squarrosa* (Licht.) Pilg.

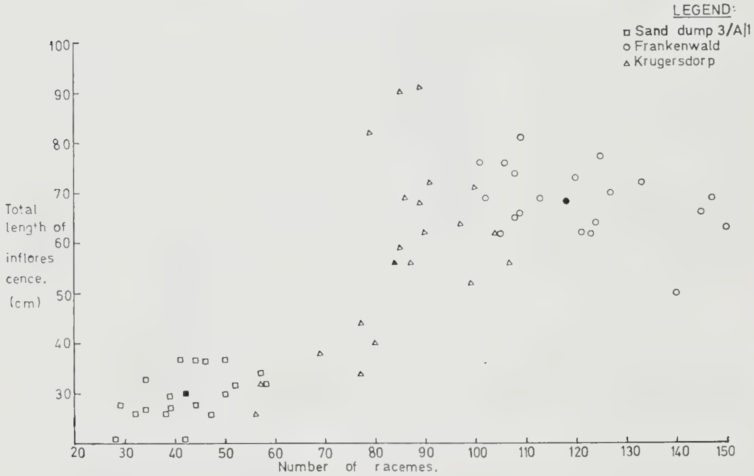


FIG. 6.
Scatter diagram for *Pogonarthria squarrosa* (Licht.) Pilg.

and the other half are found on the Frankenwald side of the discriminant index R_0, between this and the first discriminant value for Frankenwald. The R_0 value shows the two populations to be distinct, one population falling to the right and one to the left of this plane.

The polygonal graph (Fig. 5) for *Pogonarthria squarrosa* shows the sand dump population to occupy a position nearest to the central point of the radii. The intermediate Krugersdorp population seems to be closer to the sand dump population when looking at some characters and closer to the Frankenwald population when looking at others. The mean values for the most important character, the total length of the culm, substantiates this arrangement. Notice that although this is a multivariate analysis taking all characters into account, one could quite easily have introduced a univariate analysis on separate characters to show variation between values for specific characters.

This graph is extremely interesting as it shows the dwarfing effect found among individuals of the sand dump population. This is also apparent when examining herbarium specimens. The plants collected on the sand dump tend to be very small when compared with specimens collected from Frankenwald or Krugersdorp. This seems to be a size distinction only as the plants were perfect in every other detail. This phenomenon is thought to be due to the impoverished soil in which they are growing. In the case of the mine dump it may be another adaption to the consistency of the "soil", the sand being very loosely textured.

The scatter diagram (Fig. 6) for *Pogonarthria squarrosa*, endorses the intermediate position of the Krugersdorp population, when looking at the two most important characters. There is a small amount of overlap with some individuals of the other two populations. The solid symbols which represent the mean values for the three populations further substantiate the positioning of the populations in relation to one another.

Table 3 contains discriminant values for three mine dump populations of *Cynodon dactylon*, one of the species planted on the dumps. The two slimes dam populations, Booysens Reserve (3/L/20) and 2/L/4 (Consolidated Main Reef Mine) initially compared are found to be distinct by virtue of the discriminant value R_0. The values of the sand dump (3/A/1) show very close integration with the other two populations both drawn from mine dump localities. Twelve sand dump values which lie above the R_0 value are classified as belonging to population one, while the remaining eight values falling below the R_0 value can be considered to belong to population two. The *F value* of *10,056* calculated when comparing Booysens Reserve and 2/L/4 populations was highly significant at the 0,1% level; the D^2 *value* was *23,88*.

The polygonal graph (Fig. 7) for *Cynodon dactylon* clearly illustrates this relationship, showing the similarity in many characters of the three populations

Table 3.
Discriminant values for three populations of *Cynodon dactylon* (L.) Pers. For explanation, see text, p. 33.

3/L/20 Booysens Reserve Values	3/A/1 Sand Dump Values	2/L/4 Slimes Dam Values
	– 18,745 77	
	– 20,348 86	
– 21,975 62		
– 22,127 06		
	– 23,483 26	
– 23,735 75		
– 24,549 91		
– 24,858 67		
– 25,404 60		
– 25,492 29		
	– 26,085 94	
– 26,472 69		
	– 26,618 07	
	– 26,712 77	
– 26,849 64		
R1 – 27,582 3		
– 27,655 24		
– 27,924 36		
– 28,135 06		
	– 28,167 53	
– 29,058 78		
– 29,345 00		
– 29,885 91		
– 30,586 99		
– 31,124 66		
– 31,520 17		
– 32,042 69		
– 32,901 73		
	– 33,078 28	
	– 35,285 08	
		– 36,008 82
	– 36,374 69	
	– 36,708 44	
	– 37,723 51	
	R ZERO – 39,5240	
	– 39,538 47	
	– 42,779 97	
	– 42,873 47	
		– 44,605 16
	– 44,726 56	
		– 45,537 52
		– 45,944 85
	– 46,531 49	
	– 46,620 64	
		– 46,823 26
		– 47,702 85
		– 47,906 40
		– 47,947 75
	– 48,646 03	
		R2 – 51,465 8
		– 51,562 53
		– 51,763 24
		– 53,169 54
		– 54,054 40
		– 54,683 87
		– 54,951 31
		– 55,519 13
		– 55,682 95
		– 57,484 95
		– 58,101 26
		– 58,390 56
		– 61,477 43
	– 91,137 76	

which are closely integrated. The Booysens Reserve population, with the smallest mean values, forms the polygon lying nearest to the centre point of the radii. An interesting feature of this graph is that all three polygons have a comparable shape, showing that there is similarity in all characters.

The scatter diagram (Fig. 8) for *Cynodon dactylon* shows a close integration of individuals of all the populations at the centre of the graph. The individuals do not show segregation into distinct population groups when these two characters are considered.

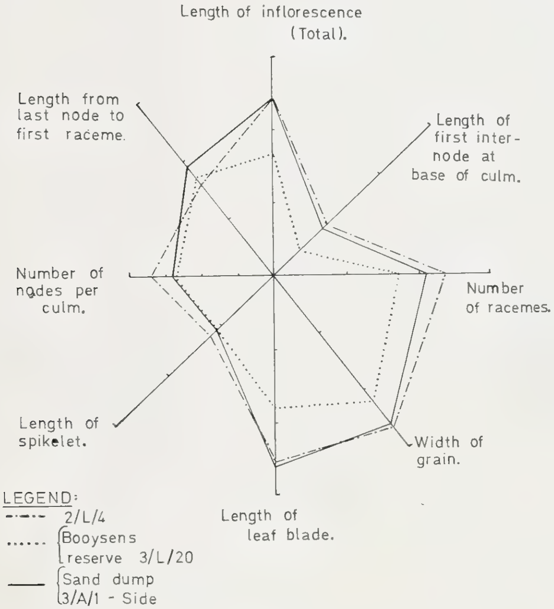


FIG. 7.
Polygonal graph for *Cynodon dactylon* (L.) Pers.

Table 4 shows the discriminant values for *Hyparrhenia hirta*. The *F value* calculated for the comparison of Booysens Reserve (3/L/20) and Frankenwald populations was *7,95* which was significant at the 0,1% level. The *D^2 value* for this analysis was *16,92*. This table shows a close integration of the discriminant values of Booysens Reserve and Krugersdorp. Both samples with the exception of four Krugersdorp individuals fall on the R_1 discriminant value side of the discriminant index. The similarity between the two populations may

TABLE 4.
Discriminant values for three populations of *Hyparrhenia hirta* (L.) Stapf. For explanation, see text, p. 33.

3/L/20 Booysens Reserve Values	Krugersdorp Values ("Natural" Population)	Frankenwald Values ("Natural" Population)
	– 18,576 63	
	– 21,492 75	
	– 22,878 17	
– 23,410 13		
– 23,727 72		
– 25,629 53		
– 26,044 62		
– 26,292 77		
	– 26,543 26	
– 27,418 76		
– 28,068 63		
	– 28,274 05	
	– 28,366 38	
– 28,522 20		
– 28,682 02		
	– 29,911 54	
R1 – 30,059 7		
– 30,140 58		
	– 30,550 51	
– 30,711 99		
– 30,827 79		
	– 30,889 66	
– 31,275 21		
– 31,623 57		
	– 32,203 43	
	– 32,470 75	
– 33,207 37		
– 33,512 91		
– 34,845 08		
	– 34,877 30	
– 34,951 57		
– 35,046 25		
	– 36,188 22	
– 37,255 86		
	– 37,418 38	
	– 37,444 02	
	R ZERO – 38,521 3	
	– 40,053 74	
		– 41,008 24
		– 41,719 44
		– 42,308 21
		– 42,787 54
	– 42,907 65	
		– 43,557 88
	– 43,949 92	
		– 43,994 96
		– 44,002 01
		– 44,376 86
		– 45,074 45
		– 45,306 37
		– 45,644 04
		– 46,545 23
		R2 – 46,982 9
		– 47,004 07
		– 47,066 82
		– 48,484 28
		– 49,397 22
	– 49,575 27	
		– 51,874 47
		– 52,895 63
		– 52,968 80
		– 53,349 44
		– 54,669 82

be due to the altitudinal similarity of the two areas from which these samples were drawn. Booysens Reserve is 1 712 metres above sea level and the Krugersdorp population was collected at 1 645 metres above sea level, whereas Frankenwald is only 1 493 metres above sea level. This can perhaps be considered to be a type of geographic variation but would require further investigation. Notice that all the Frankenwald values lie on the opposite side of the discriminant index (R_0) forming a distinct population.

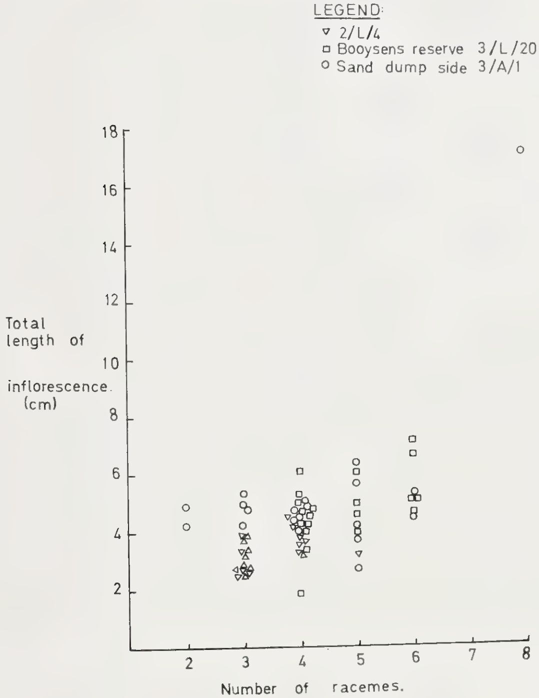


FIG. 8.
Scatter diagram for *Cynodon dactylon* (L.) Pers.

The polygonal graph (Fig. 9) for these three populations of *Hyparrhenia hirta* shows the Booysens Reserve population to be an intermediate population when considering the first three characters; width of leaf blade just above the ligule, length of floret and length of awn. The outer polygon is that of the

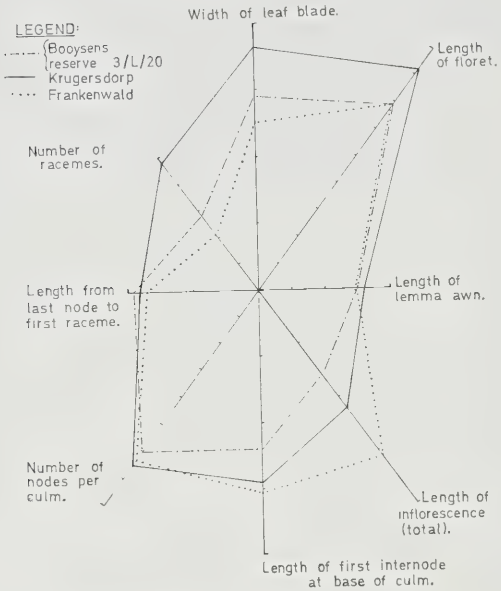


FIG. 9.
Polygonal graph for *Hyparrhenia hirta* (L.) Stapf.

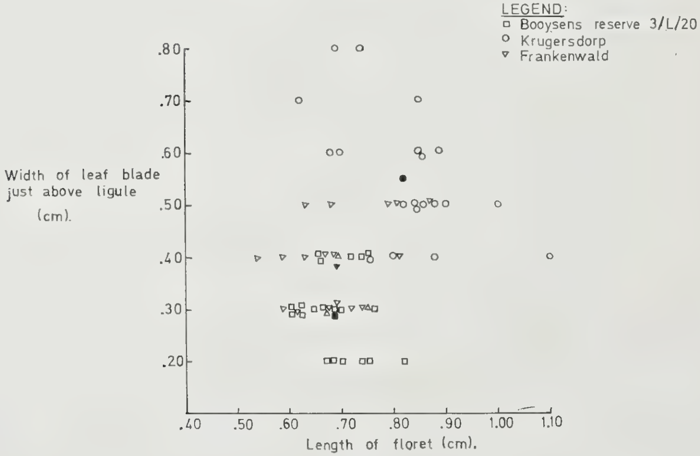


FIG. 10.
Scatter diagram for *Hyparrhenia hirta* (L.) Stapf.

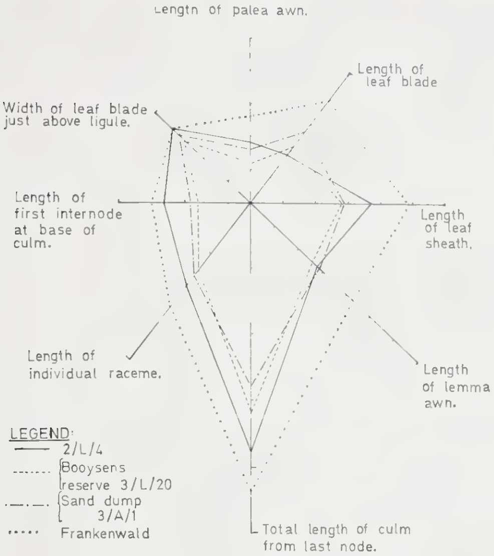


Fig. 11.
Polygonal graph for *Chloris gayana* Kunth.

Krugersdorp population while the Frankenwald and Booysens Reserve populations overlap for certain characters.

The scatter diagram (Fig. 10) for *Hyparrhenia hirta* shows individuals of the Frankenwald and Booysens Reserve populations to be closely associated when considering only the two most important characters. The individuals of the Krugersdorp population show a wide dispersion while the Frankenwald population is depicted as an intermediate population when considering mean values (which are represented by solid symbols). However, overlap at both extremes with the other two populations also occurs.

The polygonal graph (Fig. 11) for *Chloris gayana* shows the Booysens Reserve population with the lowest mean values occupying a position closest to the central point of the radii. The polygon representing the Frankenwald population is seen to be distinct, while the three mine dump populations compared have very similar polygons.

CONCLUSIONS

This study indicates that the sand dump populations were very different from the "natural" populations studied when many characters were considered.

The sand dump populations show the greatest amount of variation and remain distinct when compared with populations collected from the slimes dams. The populations collected from the slimes dams had discriminant values which compared favourably with one another and with the "natural" populations collected. With many species, overlap of discriminant values was obtained between one slimes dam population and another or with some of the "natural" populations. Although significant differences between populations were always obtained there seems to be a large amount of overlap when all characters are considered. The overall result thus indicates a high degree of uniformity among plants of populations growing on the slimes dams, and similarity to those of "natural" populations.

On Booysens Reserve, a constituent of purpleveld, *Hyparrhenia hirta*, was collected and since this work was completed *Themeda triandra* has been found growing on the following slimes dams: 3/L/14, 3/L/4 and 2/L/8. This is a step forward in the sequence of succession and seems to refute Roux's (1969) statement: "Whether succession will proceed to *Hyparrhenia*, as it has done on the cinder-covered dumps, remains to be seen. That the protected dumps will ever go to purple-veld seems unlikely, even in centuries to come. Apart from other considerations, the extension of built-up areas on all sides has pushed the purple-veld miles away and this process is likely to continue. The possibility that seeds of purple-veld grasses will reach the dumps will steadily diminish, for these seeds are not very mobile."

This study has shown that there are observable differences between "natural" and mine dump populations. Further research is necessary in order to provide an explanation for the variation and differences detected in terms of the genetic resources of the population, environmental conditions prevailing on the dumps and the general physiology of the plants.

Acknowledgments

This research was undertaken during 1971/72 in the Department of Botany, University of the Witwatersrand. During this period F. M. Thatcher held a C.S.I.R. bursary and in addition was awarded the Edward Roux Scholarship in Bioecology (University of the Witwatersrand) for 1971. Thanks are due to the Chamber of Mines Vegetation Unit and Rand Mines Properties Ltd. for permission to work on the mine dumps and for providing invaluable help.

References

Blackith, R. E. and Reyment, R. A., 1971. *Multivariate Morphometrics*. London and New York: Academic Press.

Chenik, D. J., 1960. The promotion of vegetation cover on mine slimes dams and sand dumps. *Jl S. Afr. Inst. Min. Metall.* **60:** 525–555, 744–751.

Chenik, D. J., 1963. The promotion of vegetation cover on mine slimes dams and sand dumps. Addendum. *Jl S. Afr. Inst. Min. Metall.* **63:** 212–253.

COOK, W. H., 1971. Growing vegetation on mine residue dumps. *The Clean Air Journal* **1** (1): 21–26.

DAVIS, P. H. and HEYWOOD, V. H., 1963. *Principles of Angiosperm Taxonomy*. Edinburgh and London: Oliver and Boyd.

DAVIS, J. C. and SAMPSON, R. J., 1966. Fortran II program for multivariate discriminant analysis using an IBM 1620 computer. *Computer Contr.* (*U.S.*) **4.**

DOBZHANSKY, T., 1951. *Genetics and the origin of the species*. 3rd ed. New York: Columbia University Press.

EMERY, J. R. and GRIFFITHS, J. C., 1954. Differentiation of oil bearing from barren sediments by quantitative petrographic analysis. *Producers Mon. Penn. Oil Prod. Ass.* **19** (2): 33–37.

FISHER, R. A., 1936. The use of multiple measurements in taxonomic problems. *Ann. Eugen.* **7:** 179–188.

GRIFFITHS, J. C., 1957. Petrographical investigation of the salt wash sediments. *U.S. Atomic Energy Comm. RME-3151.*

HESLOP-HARRISON, J., 1952. Statistical methods in Plant taxonomy, 2. *Taxon* **1** (5): 73–78.

HESLOP-HARRISON, J., 1960. *New concepts in flowering plant taxonomy*. London, Melbourne, Toronto: Heinemann.

IVIMEY-COOK, R. B., 1968. Phenetic relationship between species *Ononis* L. *Watsonia* **7** (1): 1–23.

JAMES, A. L., 1963. The promotion of vegetation cover on mine slimes dams and sand dumps. Addendum. *Jl S. Afr. Inst. Min. Metall.* **63:** 486–490.

JAMES, A. L., 1966. Stabilizing mine dumps with vegetation. *Endeavour* **25** (96): 154–157.

JAMES, A. L. and MROST, M., 1965. Control of acidity of tailing dams and dumps as a precursor to stabilization by vegetation. *Jl S. Afr. Inst. Min. Metall* **65:** 488–495.

KENDRICK, W. B., 1964. Quantitative characters in computer taxonomy. *Systematics Association Publication No 6*: 105–114.

KRUMBEIN, W. C. and GRAYBILL, F. A., 1965. *An introduction to statistical models in geology*. New York: McGraw-Hill Book Co.

LEFEBVRE, J. and LENNES, G., 1969. Application des fonctions discriminantes de Fisher a la classification du genire *Plagiothecium* (Musci) de Belgique. *Taxon* **18** (3): 291–299.

MELLON, G. B., 1964. Discriminatory analysis of calcite and silicate-cemented phases of the Mountain Park Sandstone. *J. Geol.* **72:** 786–809.

MILLER, R. L. and KAHN, J. S., 1962. *Statistical analysis in the Geological Sciences*. New York: Wiley and Sons.

RAUP, D. M. and STANLEY, S. M., 1971. *Principles of Paleontology*. San Francisco: W. H. Freeman and Co.

ROUX, E., 1969. *Grass: A story of Frankenwald*. Cape Town: Oxford University Press.

THATCHER, F. M., 1972. A study of the population variation amongst species of four tribes of grasses found on mine dumps as compared with those growing in natural habitats. Unpublished B.Sc. Honours Thesis, University of the Witwatersrand, Johannesburg.

WEBSTER, G., 1972. Green on gold. *South African Panorama* **17** (5): 28–31.